CRYOGENIC INFRASTRUCTURE UPGRADE OF THE FERMILAB MAGNET AND VERTICAL CAVITY TEST FACILITIES

R. Rabehl, R. Carcagno, Y. Huang, B. Norris, and C. Sylvester

Fermi National Accelerator Laboratory
Batavia, IL, 60510, USA

ABSTRACT

The Fermilab Magnet Test Facility (MTF) and the Vertical Cavity Test Facility (VCTF), both located in Industrial Building 1 and serviced by a shared cryogenic infrastructure, provide cryogenic testing of superconducting magnets and superconducting radio-frequency cavities in support of programs such as the Tevatron, US-LHC, LARP, HINS, Project X, and the ILC. While MTF must continue to support a robust magnet test program, VCTF is expected to increase its cavity test throughput by a factor of five, reaching 250 cavity test cycles per year as cavity production ramps up. A cryogenic infrastructure upgrade program has been undertaken in preparation for meeting the challenge of this additional cavity test throughput. The cryogenic infrastructure improvements include dedicated ambient temperature vacuum pumps, a helium compressor, purification skids, and additional helium gas storage. This paper will elaborate on the goals of the upgrade program, the selected equipment, and foreseen integration and operations plans and issues.

KEYWORDS: Test facilities, SRF cavity testing, magnet testing

INTRODUCTION

The Fermilab Magnet Test Facility has provided superconducting magnet testing capabilities for nearly thirty years. The facility began testing Tevatron magnets in the late 1970's, and since then it has supported magnet research and development in addition to production testing for Fermilab and collaborating institutions. Currently, the primary users of the Magnet Test Facility superconducting test stands are the LARP program, the

Fermilab High-Field Magnet Program, and the High Intensity Neutrino Source (HINS) project.

The Fermilab Vertical Cavity Test Facility consists of one Vertical Test Stand (VTS-1) that was commissioned in 2007 [1]. The design of a second VTS is in progress, and a third VTS will follow thereafter. The addition of VTS-2 and VTS-3 will enable VCTF to achieve 250 cavity test cycles per year while permitting testing of some cavity types that cannot be accommodated in VTS-1, such as HINS triple-spoke resonator (TSR) cavities, due to physical size constraints.

These additional VCTF test stands and the accompanying increase in cavity test cycle throughput plus the continuing work at MTF cannot be efficiently supported by the existing shared cryogenic infrastructure. This shared infrastructure consists of a CTI-Sulzer 1500 helium cryoplant, a 10,000 liter liquid helium storage dewar, a cryogenic distribution system, and warm (i.e., ambient temperature) vacuum pumps.

Additional equipment is required to maximize the capability, availability, and reliability of the entire cryogenic system. This equipment consists of dedicated warm vacuum pumps, a helium compressor, an oil and moisture removal system, purifiers, and helium gas storage tanks.

This paper will describe the goals of this upgrade program, the selected equipment, and integration and operation of this new equipment with the existing cryogenic infrastructure.

UPGRADE PROGRAM GOALS

The cryogenic infrastructure upgrade program has a number of goals related to cryoplant operations and the ability to support two large, distinct test programs: cavity testing and magnet testing.

One goal is to improve reliability of the cryogenics system by reducing contamination-related downtime. Contamination of the process gas is a continual threat for all cryogenic helium systems. The accumulation of contamination during lengthy periods of continuous cryogenic operations eventually leads to unplanned downtime for system warm-up and purification. Subatmospheric operations to support magnet testing at MTF is expected to continue at the present level in the coming years, but the required increase in cavity test throughput means a significant increase in subatmospheric operations support at VCTF. Even so, the upgrade program will greatly reduce the risk of contamination-related downtime. All subatmospheric flows from both the magnet test facilities and cavity test facilities will be purified before returning to the cryoplant process. In addition, the piping of the additional helium gas storage tanks has been designed to minimize the recovery time from system contamination events by allowing a sweep flow through any tank that is then sent directly to a purifier.

A second goal is to improve system reliability by providing equipment redundancy. The use of multiple, parallel purifiers and manifolded vacuum pumps will decrease the risk of downtime of both the magnet and cavity test facilities due to equipment unavailability or failure.

A third goal is to improve cryoplant operations in a number of ways, such as conservation of helium, and increased stability of operating pressures. The significant increase in required cooling water flow rates will provide the opportunity to improve water filtering capabilities and reduce cryoplant downtime for heat exchanger cleaning. Redistribution of electrical loads will free up operating margin on heavily-loaded transformers.

EQUIPMENT SELECTION

Helium Gas Storage

The increased gas storage capacity will match the maximum liquid helium inventory of the cryoplant.

The current gas storage system consists of three 113.6 m^3 (30,000 gallon) storage tanks. The addition of three more identically-sized gas storage tanks will allow the storage of 10,000 liters of 152 kPa (22 psia) saturated liquid helium (the liquid capacity and typical operating pressure of the storage dewar) at an absolute pressure of approximately 1379 kPa (200 psia), which includes a minimum operational absolute pressure of 345 kPa (50 psia) for the tanks.

Each of the three new tanks is an ASME-coded pressure vessel with a maximum allowable working pressure of 1344 kPa gauge (195 psig).

The piping of the additional helium gas storage tanks has been designed to allow flow through the tanks to a purifier, reducing the recovery time from a large contamination event.

Subatmospheric Pumping Capacity

Ambient temperature vacuum pumps are used to test magnets and cavities at temperatures below 4.5 K. This pumping capability is required for two of the five MTF test stands, the Vertical Magnet Test Facility (VMTF) [2] and the LHC Quadrupole Test Stand [3], and the one VCTF test stand, VTS-1.

The vacuum pumps currently in service reside on two skids. The larger skid is comprised of a Tuthill/Kinney® KMBD3201 blower backed by a Tuthill/Kinney® KLRC951 liquid ring pump. The smaller skid is comprised of a Tuthill/Kinney® KMBD2202 blower backed by a Tuthill/Kinney® KLRC525 liquid ring pump. The combined capacity of these systems is 6 g/s at 31 mbar. This is sufficient for testing on either of the magnet test stands or testing in VTS-1 with a dynamic heat load of up to 125 W, but the goal is to be able to maintain a 2 K bath temperature in a VTS with a 250 W dynamic heat load. This load corresponds to a 9-cell ILC-style cavity operating at a gradient of 35 MV/m with the minimum acceptable quality factor $Q_0 = 5 \times 10^9$.

The Magnet Test Facility and Cavity Test Facility currently share the two in-service vacuum pumps and therefore the two facilities cannot test simultaneously. Four additional warm vacuum pump skids identical to the larger skid already in service have been procured, and so the upgraded system will have a total of five pumping skids. A 3-D model of a typical skid is shown in FIGURE 1. The smaller skid currently in service will be taken out of service and kept as a spare skid.

Normally three of these skids will be dedicated to cavity testing while the other two will be dedicated to magnet testing. However, appropriate manifolding and isolation valves will allow sharing of pumps between the two facilities if needed because of pump unavailability due to maintenance or repairs. This will provide equipment redundancy and allow online pumping capacity to be more closely matched to the current pumping requirements. One or more pumping skids can be directed to a test stand, depending on its status.

Increased vacuum pumping capacity will have additional operational benefits for both cavity testing and magnet testing. Test stand pump-down times can be reduced. Testing of SRF cavities with high dynamic heat loads while maintaining a stable liquid helium bath temperature will be possible, and magnet quench recovery times will be reduced.

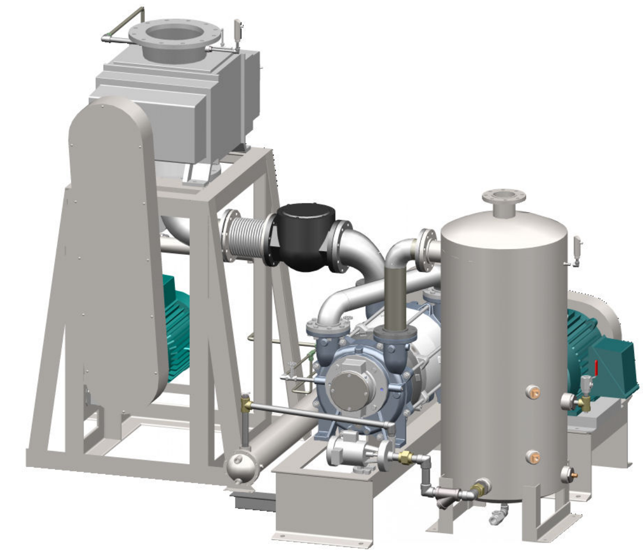

FIGURE 1. Warm vacuum pump skid. 3-D model courtesy of Tuthill Vacuum & Blower Systems® (Springfield, MO).

Compressor

The selected compressor is available from the Tevatron satellite refrigerator spare equipment pool. The characteristics and performance of this compressor system have been documented elsewhere [4] but will be briefly described here.

The compressor is a Mycom® 2016C compound, oil-flooded screw compressor with a displacement of 0.35 m^3/s (750 acfm). For inlet conditions of 1 bar (1 atm) and 21 C (70 F), the mass flow rate is 58 g/s. Analysis of VTS-1 operating data indicates that 30 g/s is the minimum required compressor capacity to support three VTS dewars, but the additional capacity of the selected machine will provide margin and minimize the impact of transients.

The compressor and all related subsystems are mounted on a single skid with overall dimensions of approximately 2.4 m (8 ft) wide, 4.3 m (14 ft) long, and 2.6 m (8.5 ft) high. Both compressor stages are driven by a single 298 kW (400 hp) motor. After being compressed, the helium flows through a horizontal bulk oil separator, water-cooled gas aftercooler, and two coalescers. The typical oil content of the helium is 2500 ppm_w after the bulk oil separator, 15-40 ppm_w after the first coalescer, and less than 0.1 ppm_w after the second coalescer. These coalescers include timed drain valves to allow the coalesced oil to return to an oil manifold for reinjection into the compressor interstage piping.

The lubricant system includes an oil pump, a water-cooled oil cooler heat exchanger, and dual oil filters.

The solid state controls system currently in service on this skid will be replaced by a modern PLC-based controls system and integrated into the IB1 cryogenic process controls system.

Oil and Moisture Removal System

An oil and moisture removal system will be placed downstream of the compressor. Like the compressor skid, the oil and moisture removal skid is from the equipment spares pool of the Tevatron satellite refrigerators. A thorough description of this system and its design and operation can be found elsewhere [4].

The oil removal skid consists of four ASME-coded pressure vessels on a 1.5 m (5 ft) by 1.2 m (4 ft) skid. The first vessel on this skid is a third coalescer stage, its 0.46 m (18 in) outer diameter identical to the first two coalescers. Many years of operating experience with the Tevatron satellite refrigerators have shown that this coalescer unit is redundant with the first two units, collecting oil only in the event of an upstream failure. Therefore it is not equipped with a timed drain valve. Downstream of the third coalescer is a 0.61 m (24 in) outer diameter charcoal adsorber to remove very fine oil mist from the compressed helium stream. The volume of the charcoal bed is approximately 0.54 m^3 (19 ft^3). Helium enters the bottom of the vessel and flows up through the charcoal bed, ensuring that any coalesced oil remains at the bottom of the vessel while the upper portion of the charcoal bed remains clean. The third unit on the oil and moisture removal skid is a 0.46 m (18 in) outer diameter molecular sieve vessel containing approximately 0.18 m^3 (6.5 ft^3) of type 4A molecular sieve pellets to remove water vapor from the compressed helium stream. Helium enters the top of the vessel and flows down through the bed. The fourth unit is a final filter housing containing a pleated filter element to remove any dust particles larger than 1 μm that were generated in the charcoal bed or the molecular sieve bed. This vessel has an outer diameter of 0.22 m (8.63 in) and is commercially available.

Helium Purification

Two helium purifiers, plumbed in parallel, and another final filter will be placed downstream of the oil and moisture removal system. These purifiers will remove air contamination from the compressed helium stream. The final filter will remove any charcoal dust generated in the purifier beds. The additional purification capability is expected to provide a significant improvement in cryogenics operational efficiency. Recovery from helium system contamination has historically been a significant factor in IB1 cryogenic system availability, and integration of additional subatmospheric test systems into the cryogenic system would only increase the contamination-related downtime if the purification capabilities are not improved.

The cryoplant currently includes two partial flow purifiers. Both purifiers were sized to remove 500 ppm_v of air from a compressed helium stream for 24 hours. The smaller purifier is rated for 4 g/s of helium flow at inlet pressures of 310-1482 kPa (45-215 psia). The second purifier is rated for 50 g/s at 2068 kPa (300 psia) but the actual flow is well below this due to piping restrictions, valve restrictions, reduced system pressures, and operational constraints.

The two new purifiers will each have a flow rating of 60 g/s at 2068 kPa (300 psia). These new purifiers are expected to be similar to the larger purifier already in service, which has a charcoal bed volume of 0.14 m^3 (5 ft^3). Liquid nitrogen for cooling the charcoal bed and gaseous nitrogen for warming the charcoal bed during regeneration will be available from the 37,900 liter (10,000 gallon) liquid nitrogen storage dewar in service at IB1.

INTEGRATION AND OPERATION

Process Integration

The simplified flow schematic of FIGURE 2 shows how this new equipment will be integrated into the cryogenic process. Several modes of operation for the new equipment are included in this schematic.

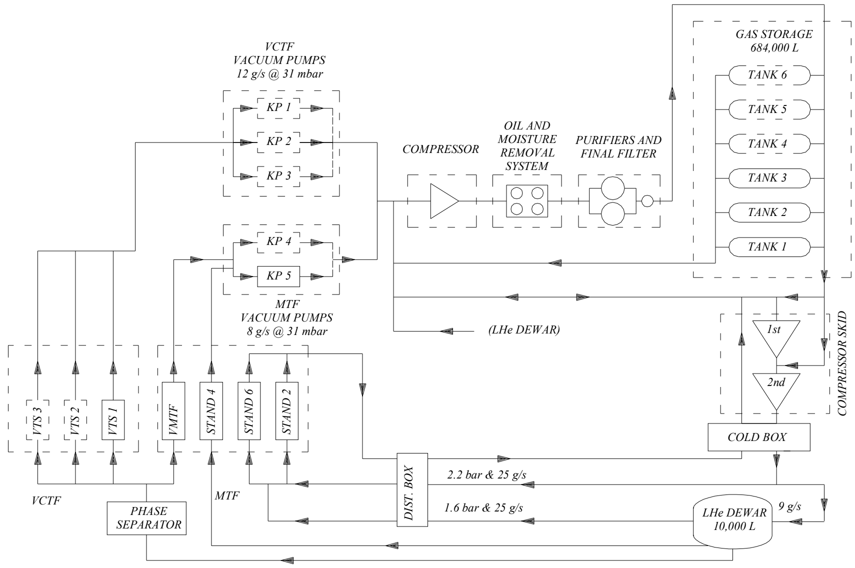

FIGURE 2. Process integration of the Fermilab IB1 cryogenic infrastructure upgrade.

All pumped flows from the Magnet Test Facility and all pumped flows and positive pressure flows from the Vertical Cavity Test Facility will be processed by the new compressor before being purified and returned to the helium gas storage tanks, which will also serve as a gas source for the compressor gas management system.

Helium gas may be pushed through any tank or combination of tanks for purification while all other tanks can be dedicated to normal ‘breathing’ operations for the cryoplant compressors.

The new compressor will be connected to the suction header for the cryoplant compressors. This will enable the new compressor to share loads returning from the magnet test stands or the cryoplant as its capacity allows. In the event the new compressor is unavailable, pumped flows from either test facility will return directly to the cryoplant compressors. This is the current mode of operations, where these flows are not purified before mixing with the process inventory.

Finally, helium boil-off from the storage dewar will be recovered, compressed, and put into the gas storage tanks during cryoplant downtime to conserve helium.

Physical Integration

Physical deployment of the new equipment requires careful consideration. Industrial Buildings 1 and 1A, where the magnet test facilities, cavity test facilities, cryoplant, and ancillary equipment are located are already very crowded.

The three new gas storage tanks (tanks #4, #5, and #6 in FIGURE 2) have already been placed adjacent to existing gas storage tank #3 and will be brought into service by the beginning of the 2010 fiscal year.

The five pumping skids will be placed together in a dedicated equipment room, a space formerly occupied by a machine shop. Renovation of this reallocated space will consider needs such as installation and maintenance, noise abatement, and oxygen deficiency hazards. A preliminary layout is shown in FIGURE 3. Pumping lines from the magnet test stands and the cavity test stands will be plumbed to this room, as will the cooling water. The discharge of these pumping skids will be manifolded and sent to the new compressor. Contamination monitoring placed at the discharge of each pumping skid will aid in troubleshooting of contamination sources.

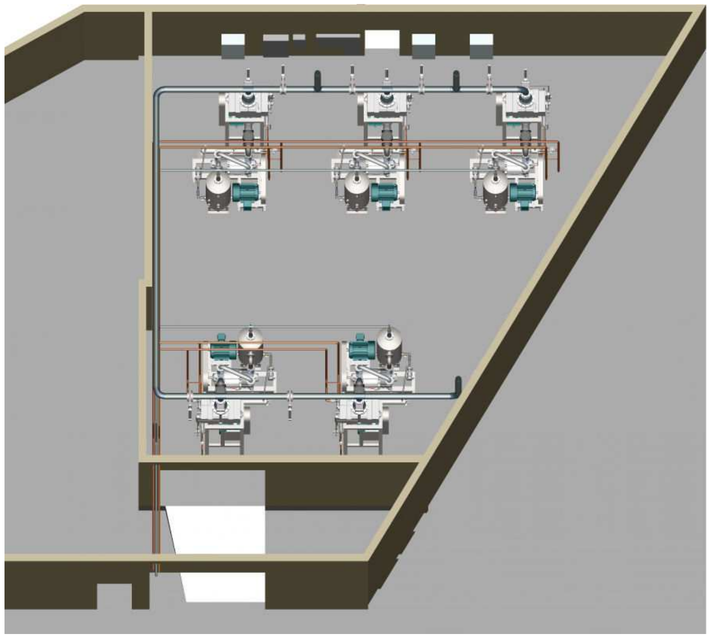

FIGURE 3. Physical integration of five warm vacuum pump skids in a new equipment room.

The compressor will be placed in a new equipment room on the north side of Industrial Building 1A (IB1A). The two existing equipment rooms of IB1A contain the cryoplant helium compressors and the associated cooling equipment. The planned location for the new equipment room is currently an open bay where high-pressure helium gas trailers can be parked, one of two locations where helium gas can be added to the cryoplant inventory. Renovation of this space needs to address the same issues as the room that will house the five vacuum pump skids.

The oil and moisture removal system, the helium purifiers, and the final filter will be placed outside. The Fermilab oil and moisture removal systems were designed for outdoor service and have been in service for many years outside satellite refrigerator buildings. A purifier design for outdoor service will require considerations such as electrical enclosures and valve and instrument selection.

Operations

Significant effort will be required to learn how to operate the new equipment effectively and in concert with the existing cryogenic infrastructure. The full compressor capacity and maximum discharge pressure of 20.3 bar (20 atm) will only be needed on occasion. Continuously running the compressor at these conditions will waste a significant amount of electric power. Liquid nitrogen usage will also be unnecessarily high if the purifiers are continuously operated with a high helium flow rate.

A conscious effort will be made to conserve energy and cryogens. Process variables and parameters such as gas management valve position, compressor discharge flow rate, and allowable flow velocities through the oil and moisture removal equipment and the purifiers will play significant roles in automating equipment to operate efficiently.

Other issues of note are automating the sequencing of pump operations and the distribution of pumping capacity when supporting multiple test stands at different phases of their test cycles, and integrating the multiple modes of system operation (purification of pumped flows, cryoplant suction pressure control, and storage dewar boil-off recovery) to ensure flexible yet safe cryogenic operations.

SUMMARY

A significant upgrade of the Fermilab Magnet and Vertical Cavity Test Facilities cryogenic infrastructure is in progress. The new equipment consists of three gas storage tanks, a helium compressor, an oil and moisture removal system, two purifiers, and four new warm vacuum pumping skids.

The equipment will be re-used from the Fermilab equipment inventory or will be procured new but based heavily on similar, in-service equipment. One advantage of this approach is that it will minimize the number of equipment procurements required and simplify the remaining procurements. A second advantage is that Fermilab experience with the equipment will provide benefits in installation, commissioning, and operations.

Most of the equipment has been selected. Efforts are now focused on process integration, physical integration, and foreseen operations of the new equipment.

Commissioning of the upgraded cryogenics system is expected during the second half of the 2010 fiscal year in order to provide a substantial increase in cavity test cycles in multiple VCTF test stands while continuing to support the magnet test programs.

In parallel with the upgrade program described here, there is an on-going effort to maximize the liquefaction rate of the IB1 cryoplant by operating at increased (design) compressor discharge pressure, identifying and eliminating system leak paths, and identifying and eliminating other system limitations. Liquid helium inventory management is also a consideration as multiple VTS test stands will allow interdewar transfer operations.

The cryogenic infrastructure upgrade of the Fermilab Magnet and Vertical Cavity Test Facilities combined with maximizing the performance of the existing cryoplant will maintain the position of IB1 as a critical test facility to support high-energy physics research programs.

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